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An Evaluation of the Hydrographic Inland Marine Acoustic Platform (HI-MAP) Survey System

Anthony Niles

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This U. S. Army Corps of Engineers has an interest in new technology and techniques in hydrographic surveying for more accurate, efficient, and productive surveys. The use of such new systems by contractors can also produce a more accurate and timely service product for the Corps. Such a system, the Hydrographic Inland Marine Acoustic Platform (HI-MAP), produced and used by John E. Chance and Associates (JECA), was evaluated in test surveys on the Mississippi River. The HI-MAP effectively integrates many new technologies, such as a phased-array sweep system and differential GPS positioning on board a trailerable twin-hull vessel, to produce a system well-suited to surveys of typical U.S. harbors, rivers, and lakes.

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PREFACE

The work being reported was done under the U.S. Army Corps of Engineers Civil Works Surveying and Mapping Program, Work Unit 32794, "Survey Systems Evaluations."

The work was performed February 18-21, 1992 under the supervision of S.R. DeLoach, Chief, Precise Survey Branch; P.J. Cervarich, Chief, Surveying Division; and R.J. Orsinger, Director, Topographic Developments Laboratory. Technical monitors from Headquarters, U.S. Army Corps of Engineers (USACE) for this project were W.A. Bergen and M.K. Miles.

The author also wishes to extend thanks and appreciation to F. W. Fowler and R. Lambert of the USACE Louisville District for their assistance in producing an accurate and valid ground-truth survey.

Mr. Walter E. Boge was Director, and Colonel Kenneth C. Kessler was Commander and Deputy Director of the Topographic Engineering Center at the time of publication of this report.

AN EVALUATION OF THE HYDROGRAPHIC INLAND MARINE ACOUSTIC PLATFORM (HI-MAP) SURVEY SYSTEM

BACKGROUND

The Hydrographic Inland Marine Acoustic Platform (HI-MAP), developed by John E. Chance and Associates (JECA), was first demonstrated to the U.S. Army Corps of Engineers (USACE) at the Corps Surveying and Mapping Conference, July 1991, in Louisville, Kentucky. The HI-MAP had many advanced systems on board, most notably the Krupp-Atlas Fansweep acoustic system that enables dense and rapid bottom surveys to be made. The Fansweep, along with other on-board systems such as the side-scan sonar and the Differential Global Positioning System (DGPS), made the HI-MAP appear well-suited to the many surveys performed by USACE.

Shortly after the Surveying Conference, USACE Headquarters directed the Topographic Engineering Center (TEC)[1] to coordinate an evaluation of the HI-MAP system for performing USACE surveys. The Lower Mississippi Valley Division (LMVD) was particularly interested in such an evaluation to determine the applicability of the HI-MAP for revetment surveys. The most favorable method of evaluation was deemed to be a survey comparison to the multi-transducer sweep system used by the Detroit District. The Detroit River is ideal for test surveys because of the firm rock bottom and low current. A hasty coordination was made between the Detroit District and JECA for the tests at Detroit by early December 1991. However, conducting the tests before the cold weather and ice flows began proved to be impossible.

Headquarters, TEC, and JECA then considered tests on the southern end of the Mississippi River where winter weather would not affect the tests. A particular selected site had a concrete revetment and is typical of other areas surveyed by the Lower Mississippi Valley Division (LMVD). Headquarters and TEC attempted to coordinate test surveys with the HI-MAP and a USACE boat and crew using tag line and lead line methods to eliminate most sounding and positioning inaccuracies. However, finding a suitable date for both JECA and an appropriate USACE crew was difficult, at best. Furthermore, river currents low enough to enable an effective tag line and lead line survey could not be found.

TEC, Headquarters, and JECA decided to conduct the survey for comparison to the HI-MAP using a total station survey instrument for positioning and two echo sounders of different frequencies for depth measurements. With carefully controlled survey procedures, this survey was evaluated to be the most accurate baseline survey reasonably possible. The tests were thus performed in February 1992 and are further described in this report.

TECHNICAL DESCRIPTION

HI-MAP Surveyor. The Hydrographic Inland Marine Acoustic Platform (HI-MAP) developed by John E. Chance and Associates (JECA) is a survey system that integrates many advanced technologies within a single hydrographic vessel. The expertise of JECA in near- and off-shore

[1]In October 1991, the name of the U.S. Army Engineer Topographic Laboratories (ETL) was changed to the U.S. Army Topographic Engineering Center (TEC). The new name will be used in this report.

bathymetry has been applied to developing a system uniquely suited to surveys of inland waterways. According to JECA, the HI-MAP is particularly well-suited to all three classes of surveys performed in the Corps of Engineers. They also claim that the system is well suited to revetment surveys, subbottom classification, subbottom density profiles, pipeline location and cover, and bridge scour surveys.

The *HI-MAP Surveyor* is a catamaran design, 38 feet long and 12 feet wide. The vessel has a 1.7 foot draft and is powered by twin diesel engines. Since the boat is trailerable, it can be ported to any location in the United States.

The primary acoustic transducers are mounted on a retractable strut between the vessel hulls slightly aft of amidship. Thus, the transducers can be stowed above the waterline when surveys are not being performed. A removable deck panel adjacent to the strut permits service access and easy transducer bar-checks. Further details on the echo-sounding transducers are given below.

The HI-MAP has an EG&G side-scan sonar, which can observe bottom features from directly below the vessel to the water's edge. The sonar is easily deployed off the bow between the vessel hulls. The sonar primarily presents qualitative information on bottom features with no true X-Y-Z scale. However, JECA is developing processing algorithms that incorporate horizontal positions and overlapping data from the primary acoustic transducers to produce true bathymetric data from the side-scan. Sonar operation and results in the current unscaled form were observed and are presented in the HI-MAP Survey section.

The HI-MAP also has an acoustic core sampling device that determines bottom density and, in some cases, composition. The two retractable transducers are mounted on the port and starboard sides of the stern deck. This system was originally developed by David A. Caulfield of Caulfield Engineering in coordination with the U.S. Army Corps of Engineers Waterways Experiment Station. The HI-MAP system, which is the first commercial implementation of the core sampling device, enables extensive bottom profiling with only occasional collection of physical bottom samples for system calibration. Due to time and logistics involved, the acoustic core sampling system was not evaluated during these tests.

Horizontal positioning is accomplished using the NAVSTAR Global Positioning System (GPS) in the differential pseudo-range mode. The on-board GPS receiver is a Magnavox 4200 and the shore reference station uses a Trimble 4000 receiver. Range corrections are transmitted every 2 to 3 seconds to the *HI-MAP Surveyor* via 460 MHz radio.

The main computer in the HI-MAP is a Hewlett-Packard 9000 system, which performs the data acquisition and processing. The HP 9000 can also plot results and create terrain models from the survey data using TerraModel™ software by Plus III, Inc. Thus, terrain visualization, volume computations, surface manipulations and basic construction designs can be performed on the HI-MAP. A 486 PC serves as the navigation computer.

Echo Sounding System. The primary echo sounding system aboard the HI-MAP is the Krupp Atlas Fansweep, a swath sounding system that covers large areas in a single pass. The Fansweep consists of two transducers mounted in a V-shape on the retractable strut. The transducers produce a fan of up to 52 sounding beams in a sector 128° wide, thus producing a swath width four times the depth. The sounding beams are 200 KHz frequency, and each beam width is 3° across

track and 6° along track.

The Fansweep operates in a minimum depth of 3 meters and a maximum depth of 100 meters. The most efficient operation is in depths of 10 to 100 meters. Depth records are produced every 0.64 seconds.

Krupp Atlas claims an accuracy of +/- (0.15 meter + 0.5% of depth). The HI-MAP uses roll and heave compensators to maintain this accuracy regardless of vessel motion.

The Fansweep has been marketed only within the last few years, and most tests of the system have thus far been conducted by the manufacturer, Krupp Atlas. In January 1991, in The Hydrographic Journal, Harre and Meyer[2] describe accuracy evaluations of the Fansweep in which the system was tested in a lock and compared to another Krupp Atlas sweep system, the Bomasweep. In the lock tests, multiple beam measurements were taken at a nominal depth of 3.9 meters. The average deviation was 4 cm, and a maximum standard deviation of 6.5 cm occurred at the outer beams. A comparison to the Bomasweep, a system consisting of boom-mounted transducers, showed a maximum difference of approximately 0.4 meter. These comparisons were made on a 1:4 (vertical:horizontal) slope over depths of 5 to 12 meters.

The Canadian Hydrographic Service conducted some of their own tests of the Fansweep in August 1991 near Vancouver, in coordination with Krupp Atlas personnel. The tests were conducted mostly in depths greater than 20 meters, and as of this report, no published results were available.

Although Krupp Atlas markets a complete Fansweep data acquisition and processing system, JECA elected to develop its own data processing software for use with the HP9000. According to JECA personnel, a significant improvement found in their software is the technique used to determine depth based on the acoustic returns. The HI-MAP uses the center of energy of the return signal rather than the initial return to determine the distance traveled by the sounding pulse. The processing procedure also features a thinning algorithm for overlapping data in which final depth values are based on localized pattern geometry and bottom statistics.[3]

The HI-MAP also has a 1 MHz Odom Echotrac sounding transducer mounted with the Fansweep transducers. The Echotrac provides redundancy and an additional calibration tool for the center beams of the 200 KHz Fansweep.

TEST SITE

Features. The selected test location was at Mile 191.5 on the Mississippi River on the left descending bank, approximately 20 miles south of Baton Rouge, Louisiana. A nearby ferry landing enabled easy access from shore to the survey vessel. Vision from atop the levee to the water's edge was clear to partially obstructed due to occasional trees. Figure 1 shows the test area at an approximate scale of 1 inch = 800 feet.

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[2]Ingo Harre and Volkhard Meyer. The Hydrographic Journal, No. 59, January 1991.

[3]Further information on the processing procedures can be found in pages 91-96 of the Proceedings of the Fifth National Ocean Service International Hydrographic Conference, February 25-28, 1992, Baltimore, Maryland.

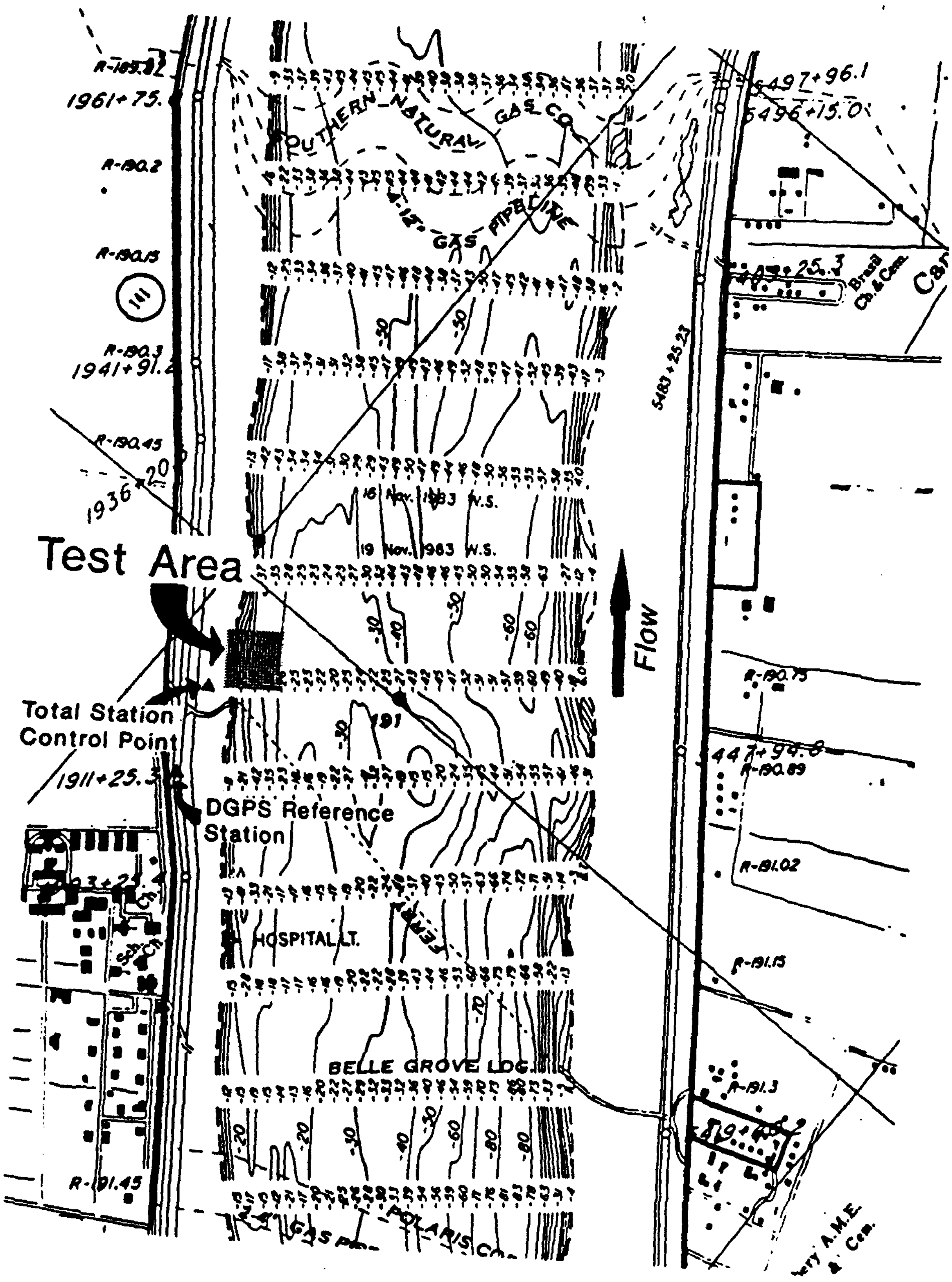

Figure 1. Test Site.

The tests were conducted over a revetment typical of those on the Mississippi. An articulated concrete mattress (ACM), constructed in 1988, extended from just below water's edge to approximately 300 feet from the shoreline. A comparison of 1 MHz and 200 KHz sounding data collected one month earlier showed that overburden material was minimal or very firm. The maximum depth observed during the tests was 40 to 45, feet and the current varied from 0 to 1.5 knots. The shipping channel is on the opposite side of the river, so tests were conducted clear of traffic, although tests were occasionally interrupted to allow ships' wakes to pass.

Horizontal Control. Survey control for the horizontal positioning in these tests was obtained from existing points PLMS 175 and PLMS 176 on the levee. The DGPS reference station used for the HI-MAP survey occupied PLMS 175, approximately 2,000 feet from the western corner of the test area. The coordinates for this station are:

N 617685.77 feet	North American Datum of 1983,
E 5347777.04 feet	Louisiana State Plane - South

A conventional traverse was run from the levee stations to establish a project baseline near the water's edge for the baseline hydrographic survey. The traverse survey was performed with a Geodimeter 140 total station to 1:12,000 accuracy. This established the accuracy of the baseline survey control relative to the DGPS control to be approximately 0.2 foot.

BASELINE SURVEY

The baseline survey used to evaluate the HI-MAP survey was designed to minimize the most common error components known to exist in hydrographic surveys. A standard land surveying total station was used for horizontal positions, and two carefully calibrated echo sounders of different frequencies were used for depth measurements. Approximately 600 independent shot points were observed over an area slightly larger than the 400-foot-square test site. Vessel navigation within the test site (only to ensure adequate coverage) for the baseline survey was maintained using JECA differential code-phase GPS referenced to the revetment baseline PI station PLMN 175, the same station referenced by the HI-MAP survey. The entire baseline survey was performed on the JECA vessel, *HI-MAP Surveyor*.

Horizontal Positioning. Horizontal coordinates for the baseline survey were obtained with a standard land surveying electronic total station (Geodimeter 140), operated by Louisville USACE District surveyors. The total station was positioned on the western station of the project baseline. Shot points to the survey boat were observed/recorded to ± 1 second (horizontal and vertical angles) and electronic distance measurement (EDM) distances to ± 0.01 foot. An omni-directional retro-reflector prism array was mounted directly atop the vessel transducers. Positions were taken with the vessel static and in motion. To minimize errors due to the total station 0.4-second update rate and position-depth recording delays, vessel velocity never exceeded the river current, approximately 1.5 knots.

Depth Measurement. Depths at each shot point were simultaneously measured by an Echotrac 200 KHz transducer (2.75° beam-width) and 1 MHz transducer (1° beam-width). Both analog and digital readings were made at each shot point. Depth measurements, or "marks", were coordinated with the total station operator through voice radio. A data collection program developed

for these tests enabled sequential annotation of the recorded depths. During post-processing, the depths were thus easily matched with the similarly annotated positions. Both acoustic systems were calibrated by velocity meter readings and standard bar-checks, performed before and after the survey.

Bar-check results at 1-meter intervals indicated no differences greater than 0.1 foot at any depth, well within the interpretive resolution of the bar-check process. Depths were referenced/corrected to an arbitrary river stage of 10.20 feet, as observed at a staff set on the revetment in the test site. Short-term stage variation was less than 0.05 foot. A leadline check showed no difference between either the 200 KHz and 1 MHz readings. Real-time comparisons between the transducers and analysis of the digital results indicated a variance of approximately $\pm$0.1 foot.

Lead-line soundings at each shot-point were originally planned for ground-truth comparisons to the Echotrac soundings and the HI-MAP survey. However, with the depths encountered and the slight river current, the lead-line results were found to be less reliable than the Echotrac soundings. The USACE test personnel concluded that lead-line soundings of 0.5 foot accuracy or less would have been possible only in zero river current (an unrealistic condition for a revetted area).

Accuracy Assessment of Baseline Survey. The positional accuracy of each baseline survey-measured depth, relative to the DGPS Station PLMN 175, is estimated to be within 1.7 feet RMS. A 0.4 second time lag for the total station distance measurements with a maximum vessel speed of 1.5 knots (due to river current) produces a 1.0 foot positioning error. A second time lag is due to operator delay in coordinating time marks between the total station and transducer operators. Up to a 1 second delay is possible, although careful operating procedures assured that operator time lag was 0.5 second, or less, 80 percent of the time, resulting in a 1.3 feet positioning error. The accuracy of the surveyed coordinates for the total station control point is 0.2 foot. Positioning error due to total station instrument inaccuracy is negligible. The overall positioning accuracy is considerably better than the 1 to 5 meter RMS levels normally associated with conventional hydrographic survey positioning (i.e. range-azimuth, multi-ranging, GPS code-phase, etc.).

The accuracy of the depths as measured by the Echotrac transducers is evaluated to be $\pm$0.2 foot. Bar-checks, performed before and after the survey at depths of 10 to 27 feet, indicated consistent accuracy, and results from the two transducers agreed to 0.2 foot or better. The additional error due to the $\pm$1.7 feet positioning accuracy, combined with the $\pm$0.2 foot transducer error, can result in a depth error of $\pm$0.6 foot. This represents the error at the steepest side-slope, 1:4 (rise:run), where errors in measured depths are expected to be the largest. However, most of the test area has less gradient, and the surveyed depths are accurate to 0.5 foot or less.

Overall, the baseline survey represents the most accurate depiction of the test site that could have been obtained; by using the most accurate horizontal positioning and vertical acoustic measurement devices available. Higher accuracy from a tag-line/leadline survey system would not have been obtainable at this site.

HI-MAP SURVEY

The designated test area was surveyed with the HI-MAP's Fansweep sonar system in a typical procedure used by JECA for bottom surveys. Results were completely edited and processed by JECA for comparison to the baseline survey.

Calibration. A "blueline" calibration was performed the day before the tests. This procedure calibrates the outer beams of the Fansweep by comparing overlapping depth measurements obtained from test runs over flat bottom terrain. On the first day of tests, the middle beams were bar-checked and calibrated. Additionally, velocimeter readings were taken at varying depths and applied to the Fansweep calibration. Again, further information can be obtained from the Hydrographic Conference Proceedings (see footnote 3).

Test Survey. Following the bar-checks and approximately 3 hours before the baseline survey, the HI-MAP test survey was performed. Survey lines were run parallel to the shoreline and spaced to allow 50 percent overlap. The survey lines were 800 feet long and extended out approximately 500 feet from the shoreline. Total survey time was 55 minutes.

Side-Scan Demonstration. Although the purpose of these tests was to evaluate the bottom-mapping ability of the HI-MAP, the USACE test personnel did have the opportunity to see the operation and results of the HI-MAP side-scan. On the second day of tests, the side-scan was operated over the slope of the test area, which consisted of ACM revetment and, at depths of 15 feet or less, loose stone. The analog paper copy showed a dense collection of acoustic returns and shadows that require expertise and experience to fully interpret. However, certain features were readily apparent, even to untrained observers. The side-scan showed the revetment to be in stable condition with some occasional overburden. However, side-scan results at another site showed a different condition, and the chart is included in this report along with further description below.

Immediately after the two days of testing, the HI-MAP traveled to Mile 183 on the Mississippi to examine a revetted area of concern to the New Orleans District. Personnel from JECA had been involved in contract revetment surveys in various areas on the river for the New Orleans District. At this particular location, district personnel believed that a gap in the revetment existed, and they wished to have JECA verify this suspicion. The area was surveyed by JECA with the Fansweep, and an analysis was performed with the side-scan. The side-scan results depict some important features, and the output chart is shown in Figure 2. The top picture clearly shows the ACM on the left side, with the individual concrete blocks discernable. Beyond the ACM to the right is a large hole in the bottom terrain approximately 70 feet deep, apparently caused by damaging river currents. The profile chart along the top of the picture offers a "side view" and further illustrates this depression. The bottom picture is a continuation of the side-scan chart. Fragments of ACM are visible in various orientations, indicating revetment that has been twisted and damaged by river currents.

The side-scan on the HI-MAP appears to be a valuable tool for evaluating the condition of revetments or other underwater structures. The device can distinguish features as small as a few feet and is clearly capable of finding gaps in revetment coverage.

ANALYSIS OF RESULTS

Comparison of Surveys. A digital terrain model (DTM) from the 2,800 X-Y-Z Fansweep data points collected in the test area was created on board the HI-MAP using TerraModel™ software, produced by Plus III Software, Inc. Such a terrain model enables full use of the dense data set produced by the sweep system for applications like visualizing 3-D terrain, computing volume and determining interpolated survey points. Also, JECA can produce Intergraph-compatible design (DGN) files and terrain triangulated network (TTN) files, such as may be required by Corps districts,

Figure 2. Side-Scan of Revetment Area.

on board the *HI-MAP Surveyor* or at JECA offices. For these tests, only TerraModel™ files were used.

An initial comparison between the baseline and HI-MAP surveys was accomplished by inspecting overlaying plots of the survey data points. The comparison showed good agreement and no significant discrepancies.

At JECA offices, interpolated points were extracted from the HI-MAP DTM that corresponded to the baseline survey points obtained from the 200 KHz and 1 MHz Echotrac surveys. Comparison of the interpolated and baseline points is as follows:

200 KHz Echotrac vs. HI-MAP Fansweep

Mean:	+0.032 feet
Average Deviation:	$\pm$0.4 feet
Maximum Deviation:	+2.8 feet
Number of Points Compared:	478

1 MHz Echotrac vs. HI-MAP Fansweep

Mean:	+0.030 feet
Average Deviation:	$\pm$0.4 feet
Maximum Deviation:	+2.7 feet
Number of Points Compared:	478

The mean difference between the two surveys indicates no systematic biases between the baseline and HI-MAP surveys. This small difference is well within the calibration accuracy ($\pm$*0.1 foot) of either* system. This lack of any bias between the two surveys is considered the most important and critical result of the tests, since such biases would adversely impact construction measurement and payment computations.

As expected, the maximum deviations occurred on the side-slope where positioning inaccuracy is most significant. Again, the error in this area was mostly random. A further analysis of the five largest deviations was performed by varying the positions on the DTM by 10 feet (anticipated positioning accuracy) in various directions. This position variation enabled exact match of the baseline and HI-MAP depths, which indicates that depth deviation in the slope areas is primarily due to positioning inaccuracy.

Comments on Positioning System. The USACE test personnel used an "end-product approach" to the analysis of the HI-MAP, where only the final survey data was analyzed. Significant discrepancies in the echo sounding or positioning systems would be manifested by large deviations in the baseline and HI-MAP survey data sets. As presented above, no large deviations occurred, and JECA's claim of an accuracy of 3 meters RMS or better for the positioning system is regarded as valid. Thus, JECA has successfully utilized DGPS for USACE Class I survey positioning.

While conducting the baseline survey, the USACE personnel did have a unique opportunity to compare DGPS with a conventional and more accurate system. Because DGPS was used for navigation, a file of DGPS positions was easily produced, which later enabled a comparison of over 400 DGPS and total station positions. This comparison does not give an accurate assessment of the HI-MAP positioning, since the filtering routine applied during normal HI-MAP surveys was not utilized

for this navigation phase. The DGPS/total station comparisons are therefore not included in this report, although the data is being used by TEC for current studies of DGPS. This data should further enable the drafting of guidelines for the effective implementation by USACE districts of DGPS for hydrographic surveying.[4]

CONCLUSIONS

The HI-MAP system uses many state-of-the-art technologies to provide complete and detailed hydrographic surveys. The Krupp-Atlas Fansweep phased-array system provides far greater coverage density than single transducer systems commonly used by USACE. This feature makes the HI-MAP particularly suitable for surveys of revetments or other underwater structures that require much detail for accurate analyses. The Fansweep system also enables more accurate volume estimates for channel or harbor dredging.

The HI-MAP uses the satellite-based differential Global Positioning System (DGPS) for determination of horizontal positions. Analysis of the final smoothed positions, as computed and used by the HI-MAP, was not possible, although JECA claims an accuracy within 3 meters RMS. This accuracy is evidenced by the close correlation of the final survey results.

The main data logging and processing system on the HI-MAP is an HP 9000 Unix workstation. This computer is needed to handle the high volume of data produced by the Fansweep acoustic system. The data logging and processing software, produced in-house by JECA, features calibration and thinning routines to ensure accurate X-Y-Z coordinates across the entire swath width. The JECA personnel can produce post-processed survey files, data plots, 3-D color plots, and volume computations on board the HI-MAP. Also, JECA can produce Intergraph DGN and TTN files at their Lafayette, Louisiana offices.

The *HI-MAP Surveyor*, a catamaran design 38 feet long and 12 feet wide, is well-suited to operations in inland rivers, lakes, and harbors, and is trailerable to any location in the United States.

A comparison of the HI-MAP Fansweep results with a carefully controlled baseline survey using a 200 KHz and a 1 MHz echo sounder revealed an average deviation of less than 0.5 foot. The larger deviations were on the gradient areas, as expected, where positioning inaccuracies become significant. The tests were conducted on a 400-feet-square area over an articulated concrete mattress revetment typical of those on the Mississippi River. The HI-MAP is deemed to be applicable to USACE Class I, II, and III surveys, as defined in the Engineer Manual *Hydrographic Surveying*, 1110-2-1003.

The HI-MAP also has a side-scan sonar system that is capable of bottom analyses from directly below the vessel to the waterline. The side-scan presents graphic detail of bottom features as small as a few feet, and it would be an excellent tool for such applications as evaluating revetment conditions and locating wrecks or other objects.

The HI-MAP appears to be an excellent tool for the many different types of surveys

[4]Further information on DGPS can be obtained from the USACE Engineer Manual EM 1110-1-1003 or the Civil Works Construction Guide Specifications CW 01334.1, 01334.2, and 01334.3.

performed by USACE personnel. The advanced sonar and positioning systems are well integrated to produce surveys of far greater detail than systems currently used by USACE and that are at least as accurate. It should be noted that the results from a system as complex as the HI-MAP are very dependent on the expertise of the operators and technical support staff, such as was found with the JECA personnel. Proper integration, operation, maintenance, and trouble-shooting of a HI-MAP-type system requires, at a minimum, expert personnel in underwater acoustics, software engineering, and hydrographic surveying. Such a system could successfully be utilized by less specialized or by hydrographic survey personnel alone if the systems are made more robust and "user friendly" by the manufacturers.